Section 4

Chapter 1

Drivers

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1. Introduction

The adverse effects of human activities in the marine environment require a conceptual understanding of a cause-consequence-response framework based on knowing the basic human needs related by the environment, the activities required to satisfy those needs and the pressures (mechanisms of change) emanating from those activities (Elliott and Kennish, 2024). This encompasses both natural and human realms and frameworks (i.e. the socioecological-environmental system) to better understand how changes are manifested (Bograd and others, 2019; Smith and others, 2025). The prevention and mitigation of actual or potential adverse changes require effective governance and management.

Marine-based human activity sectors include: physical restructuring of catchments, coastlines and the seabed; extraction of non-living and living resources; energy production; cultivation of living resources; transport, urbanization and industrial uses; tourism and leisure; and security and defence. An additional sector relating to nature conservation, protection and restoration may be included .[1]

Drivers are widely regarded – including by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), the Intergovernmental Panel on Climate Change (IPCC), the European Environment Agency and regional seas conventions – as any natural or human-induced factor that directly or indirectly changes the ecosystem (Millennium Ecosystem Assessment, 2003; Haines-Young and Potschin, 2018; IPBES, 2024; Elliott and Kennish, 2024; Balvanera and others, 2019, 2020; Diaz and others, 2018; Hill and others, 2021; European Environment Agency, 2019; Blanco and others, 2014). In the present chapter, the human drivers having the greatest influence on the marine environment and its sustainability are:

(a) Population growth and demographic changes, and demand for resources (e.g. food, space or energy);

(b) Economic activity, as both the cause of and reasons for many of the activities leading to the pressures on natural and social systems;

(c) Technological advances, as activities that may create both beneficial and adverse consequences;

(d) Changing governance structures and social, economic and geopolitical instability: these are both the responses (as management measures) and results of demand for resources;

(e) Climate change, biodiversity loss and pollution resulting from the activities and effects of an increasing population and its demands for goods and benefits, and their production, transport and ability to fulfil basic human needs (e.g. food, security, employment and recreation). The resulting pressures include an increase in atmospheric greenhouse gases, as well as contamination leading to pollution as an

[1] See https://oap.ospar.org/en/ospar-assessments/quality-status-reports/qsr-2023/qsr2023-reference.

adverse effect on all levels of biological organization. The drivers are also influenced by demographic changes in the form of climate migrants.

2. Drivers of change in the marine environment

Population growth and demographic changes

Although the global human population increased from 7 billion in 2011 to 8.2 billion in late 2024, [2] the growth rate has decreased, from 2.1% in 1968 to 0.87% in 2024, but the global population is nevertheless projected to reach 9.7 billion by 2050. The decrease in the growth rate results from a declining birth rate, especially in the global North, with lower mortality rates and an increased lifespan resulting from improved health. This is accompanied by the increasing average age of the global population.[3]

An estimated 37% of the global population, i.e. 3.03 billion people, live within 100 km of the coast, twice the overall average population density (Cosby and others, 2024). Around 11%, or approximately 900 million people, live on land that is less than 10 m above sea level, known as the low-elevation coastal zone (Barbier, 2015), and this is projected to rise to more than 1 billion by 2050.

Increasing urbanization and industrialization, including exploitation, are among the most important trends in the coastal area. They also increase pressure on river catchments given the increased use of resources (water, food, physical resources and space), and greater transport and energy use. This leads to the need to remove waste or for uncontrolled discharge of waste (see sect. 4, chap. 6).

Economic activity

Economic activity, measured as gross domestic product (GDP) per capita, has grown steadily globally, with very high geographical variability, although manufacturing has decreased and services have increased in specific areas. Growth has slowed as a result of a declining trade volume, especially in light of global shocks.

Given that 41–45% of global economic activities are concentrated along the coast (Patterson and Glavovic, 2013), increased coastal urbanization and industrialization have enhanced demand for societal goods and benefits, including energy and other resources, and led to changes in tourism and recreation. This in turn has expanded the use of natural resources through extraction, production, consumption and waste generation. This may be termed the increasing industrialization of the seas.

Total energy demand, measured in million tons of oil equivalent (Mtoe), grew from 13,267 Mtoe in 2014 to 13,978 Mtoe in 2018.[4] Global energy consumption accelerated in 2023 by 2.2%, which was faster than its average growth rate of 1.5% per year from 2010 to 2019.[5] At the same time, primary energy intensity, which reflects energy use in the global economy, declined to 0.8% in 2021 from an average of 1.8% in the previous decade.[6]

The reduction in GDP generated per unit of energy used is the result of several short-term factors, such as the reduction in fossil fuel-based electricity generation, together with an increase in less energy-intensive

[2] See https://ourworldindata.org/economic-growth.
[3] See https://population.un.org/wpp.
[4] See https://yearbook.enerdata.net/total-energy/world-consumption-statistics.html.
[5] Ibid.
[6] See www.iea.org/reports/sdg7-data-and-projections/energy-intensity.

industries. Many countries have reduced fossil fuel use, especially with the closure of coal-fired power plants, while renewable energies have expanded. Improved technologies have increased marine-based renewables, especially offshore wind power, although other marine energy technologies, such as wave and current turbines, are at the prototype stage, with usage increasing. In 2023, the global operational capacity for marine renewable energy reached 527 MW, while the cumulative capacity was 67.8 MW for emerging ocean technologies, 41.4 MW for tidal stream energy and 26.4 MW for wave energy[7] (see subsect. 5A, chap. 3). In 2023, mature marine energy generation technologies enabled 8.8 GW of new installations, bringing total global offshore wind power capacity to 64.3 GW. This reflected an annual growth rate of 16%, representing 7% of global energy production.[8]

The economic benefits of extracting marine biological resources (fish, shellfish and algae) are increasing as the coastal population grows. Mariculture is increasing and starting to move offshore to floating cages as well as having an inshore and estuarine or fjordic culture. Marine capture fisheries production has remained relatively stable in the past three decades, but the sustainability of fisheries resources is of concern.[9] According to the latest assessment of the state of marine fishery resources by the Food and Agriculture Organization of the United Nations (FAO), 64.5% of fish stocks are considered to be biologically sustainable.[10] Wild fishing and mariculture activities have an impact through overfishing, by-catch (the accidental taking of unwanted species and sizes), habitat loss and the transfer of pests and diseases (Haas and others, 2020) (see subsect. 5A, chap. 1).

There are continuing demands for and increases in the extraction of nearshore coastal and marine aggregates and minerals; sand and gravel mining is mostly inshore for construction and beach nourishment and, from 2012 to 2019, there was an increase in sand extraction, with 4 billion to 8 billion tons extracted annually (see subsect. 5A, chap. 7).[11] In addition, the exploration potential for offshore deep mineral mining has led to proposals for mining deeper resources of ferromanganese crusts, manganese nodules, seafloor sulphides, phosphorites and phosphates, and even marine diamond mining.[12]

Marine biotechnology is an emerging global industry for food and feed, cosmetics, aquaculture, agriculture and chemicals, diversifying into industrial enzymes, functional foods, cosmeceuticals, pharmaceuticals, biomaterials, bioprocessing and medical devices. The global market for such products and processes is predicted to reach $6.4 billion by 2025 (European Marine Board (EMB), 2017). The 10 largest companies in eight core ocean economy industries generate, on average, 45% of each industry's total revenue, and the 100 largest corporations account for 60% of total revenue (Virdin and others, 2021).

The coronavirus disease (COVID-19) pandemic greatly affected social, economic and environmental ocean aspects. Social lockdowns and travel restrictions decreased tourism and recreation in coastal areas, altering community dynamics that rely on ocean access for leisure and livelihoods (United Nations Educational, Scientific and Cultural Organization (UNESCO), 2021; Bennett and others, 2020). Economically, many fishing and tourism-dependent industries and communities faced significant losses due to reduced demand and operational challenges, increasing unemployment and financial insecurity

[7] See www.oceanenergy-europe.eu/wp-content/uploads/2023/03/Ocean-Energy-Key-Trends-and-Statistics-2022.pdf.
[8] See www.gwec.net.
[9] See https://openknowledge.fao.org/items/8ab20ccf-1e9d-4ae6-836c-ca770d16da01.
[10] See https://openknowledge.fao.org/items/8bf1f881-9208-4c59-86e2-9ada635960dd.
[11] See www.unep.org/news-and-stories/press-release/unep-marine-sand-watch-reveals-massive-extraction-worlds-oceans.
[12] See www.usgs.gov/centers/pcmsc/science/global-seabed-mineral-resources.

(FAO, 2020; International Maritime Organization (IMO), 2020). Environmentally, reduced human activity in the short term improved water quality, decreased marine pollution and human impacts and improved biodiversity. However, the long-term consequences of increased discarded plastic waste from medical supplies and single-use items pose new challenges (Zhang and others, 2020; Cozzoloi and others, 2020; Harrison, 2020). While the pandemic highlighted the need for sustainable practices, it also emphasized the vulnerability of ocean-dependent communities and ecosystems.

Technological advances

The growth of sustainable inclusive ocean economies, increasing urbanization and increasing industrialization on land and at sea have been accompanied by marine technological advances, each with their own activity, pressures and effects footprints (Elliott and Kennish, 2024). For example, fisheries technologies have both increased catches and helped to reduce by-catch. There have been technological advances in monitoring, surveillance and catch reporting, and in the use of artificial intelligence and environmental DNA in fisheries litter reduction and in seabed scanning in relation to habitat change and resource extraction (e.g. seabed mining). Improved monitoring and control of fishing, including the use of automatic identification systems and vessel monitoring systems, is aimed at reducing illegal, unreported and unregulated (IUU) fishing, as required in the context of Sustainable Development Goal 14 (Andriamahefazafy and others, 2022).

On land, urban and industrial energy production and use have changed through technological innovation, leading to greenhouse gas reductions. However, such reductions are not uniform nationally, regionally and globally.

Changing governance structures and geopolitical instability

Governance is the framework by which an entity (country, company or organization) is directed and controlled. At a country level it emcompasses policies, political action (including parliamentary action), public administration and legislation. Plans and programmes should then aim to implement these policies by means of technical measures (Cormier and others, 2022; Glavovic, 2024). Governance is broader than, but an integral part of, management in that it governs the political, economic and societal realms. Marine management operationalizes governance by encompassing the public and private realms, with Governments implementing policies, resulting in laws, which then require rules and regulations (Glavovic, 2024; Elliott and others, 2025). Marine industries in turn adopt operational aspects to support economically and societally successful and sustainable businesses. Governance should be vertically integrated, from the local to the global level and vice versa, and horizontally integrated across sectors. In turn, each legal instrument requires an administrative competent body, usually at the national level, for implementation, again resulting in each country having a plethora of often overlapping statutory bodies (see sect. 3).

Global initiatives are underpinned by regional agreements, notably regional seas conventions, some of which are promoted by the United Nations Environment Programme (UNEP), and many of which produce regular quality status reports. Regional initiatives are underpinned by national laws and regulations that, despite differing global inequalities, are broadly similar across countries.

Climate change, biodiversity loss and pollution

Climate both influences and is influenced by oceanic conditions, and climate change is regarded as a range of exogenic unmanaged pressures in a marine area. While the causes of climate change emanate outside that area, requiring them to be managed globally, the consequences, such as increased storminess, erratic weather patterns and acidification, are within that area and so require local management, including adaptation to relative sea level rise. The recent IPBES thematic assessment report on interlinkages among biodiversity, water, food and health (2024)[13] emphasizes the intertwined nature of biodiversity loss, climate change, public health, food, water and energy, among other things. These influence coastal livelihoods and sustainability prospects.

The IPCC *Special Report on the Ocean and Cryosphere in a Changing Climate* (IPCC, 2019) and the sixth IPCC assessment report [14] show global climate change trends and future projections under different greenhouse gas scenarios (the so-called shared socioeconomic pathways scenarios (see sect. 4, chap. 3; and subsect. 5B)). Global carbon dioxide (CO_2) emissions increased from 30.4 $GtCO_2$ in 2010 to 37.55 $GtCO_2$ in 2023. This has decreased polar and altitudinal ice cover and sea oxygen levels and increased ocean acidification and extreme events such as coral bleaching (see sect. 4, subchap. 5D).

The loss of Arctic sea ice is opening navigation routes and therefore access to previously inaccessible resources, as well as providing increased vectors of non-indigenous species (NIS) (see sect. 4, chap. 6). There will also be increased demand for resources, such as water for agriculture in increasingly arid areas, and the movement of fish stocks polewards. Climate change and its growing marine pressures are increasing human population migrations, not least from arid interior areas to coastal areas, but also from vulnerable coastal areas.

Biodiversity loss both reflects and indicates a decline in ocean health and is therefore a driver for associated changes such as a loss of ecosystem services and the resulting societal goods and benefits (UNEP, 2020). It also weakens ecosystem resistance and resilience to threats, including climate change, pollution, NIS input and overfishing, further accelerating the decline in ocean health (UNEP, 2020).

Contamination and pollution, such as plastic waste, agricultural run-off, sewage and chemicals, are major contributors to the decline in ocean health (UNEP, 2021). Nutrient pollution from agricultural run-off and urban and industrial discharges cause eutrophication, resulting in harmful algal blooms that deplete oxygen in the water, cause fish kills and create abiotic "dead zones" (UNEP, 2016). Plastic pollution creates significant environmental concerns. The ocean water column is a major, transitory sink for microplastics, forming a suspended concentration (Harris and others, 2023). This and the increasingly large major gyres of ocean-floating plastics have led to negotiations on a legally binding treaty to cover the full life cycle of plastics (Maes and others, 2023).

In addition, plastics and harmful chemicals such as heavy metals and pesticides are experiencing bioaccumulation, disrupting reproduction and growth, and entering the food chain to affect larger organisms, including humans (Maes and others, 2020; Elliott and Kennish, 2024). This degrades critical habitats such as coral reefs and mangroves, reducing biodiversity and essential ecosystem services, including coastal protection and carbon storage (Halpern and others, 2008; Harris and others, 2021).

[13] See www.ipbes.net/nexus-assessment.
[14] See www.ipcc.ch/assessment-report/ar6.

Furthermore, increased CO_2 emissions have led to ocean acidification, negatively affecting shell-forming organisms and disrupting marine ecosystems. Pollution thus poses a significant threat to ecosystem health, resistance and resilience, requiring effective pollution management and mitigation.

3. Key region-specific issues or aspects associated with drivers

There are geographical variations in all drivers described in the present chapter, especially between the global North and the global South, but also in terms of economic wealth, population demographics, technological status and susceptibility, such as to climate change and geopolitical instability and the resulting impacts.

Population growth and demographic changes

Fertility rates and therefore population growth in high-income regions, notably the global North, continue to be lower than in middle- and low-income regions, especially in equatorial areas and the global South (Baxter and others, 2017). However, fertility rates coupled with an ageing demographic, even in high-income countries, creates challenges, although population growth in such countries results partly from economic and climate change migrants (legal and illegal entries). There is high population growth in sub-Saharan Africa, Central and Southern Asia and Eastern and South-Eastern Asia. The average in the least developed countries[15] was 2.3% over the period 2015–2020, over twice the rate globally. This influenced the achievement of sustainable development and the conservation of coastal and marine areas, especially in areas vulnerable to climate change, climate variability and sea level rise (United Nations Department of Economic and Social Affairs (UNDESA), 2019).

Migration to coastal areas (Ekoh and others, 2023) requires increased adaptation of coastal cities to climate change (Wannewitz and others, 2024). Although globally not uniform, the rise in the number of global coastal megacities from 25–33 in 2018 to 44–45 in 2023 puts more populations at risk of flooding, erosion, subsidence and increased storminess and storm surges.

In 2022, the global total fertility rate was 2.3, the same as the global fertility replacement rate for 2010–2015, thus creating a significant milestone at which the global fertility rate equals the global replacement rate.

Economic growth

The global financial crash in 2008 and the COVID-19 pandemic increased economic challenges and the variable abilities of rich and poor countries to withstand such shocks; for example, political instability, the effects of conflicts and/or climate change have adversely affected economic growth. Changes to shipping routes, including the opening up of Arctic routes, and accidents or piracy affect global trade (e.g. diversions from the Suez Canal).

It is notable that, together with increased economic growth globally, coastal and estuarine urbanization and industrialization have increased disproportionally but with international and intranational discrepancies. Rising wealth in some areas and a growing middle class, especially in the global South, have increased tourism and recreation, with greater coastal development and infrastructure. In 2024,

[15] See www.un.org/ohrlls/content/about-us.

global international tourism reached 97% of pre-pandemic levels and had increased in some areas.[16] Similarly, agricultural changes and deforestation produced demographic changes.

Technological advances

Marine technological advances, especially in areas beyond national jurisdiction, expand sustainable inclusive ocean economies and the exploitation of marine resources. This includes increased aquaculture and renewable energy extraction moving offshore and proposals for deep-sea mineral mining. Effective international governance, such as through the International Seabed Authority (ISA) and the United Nations Convention on the Law of the Sea, is required to enhance national cooperation and address international transboundary issues, especially to obtain societal goods and benefits while at the same time protecting marine ecological structure and functioning. Technology transfer is needed between the most and least developed countries and regions to ensure the sustainable development and exploitation of marine resources. This also includes increased monitoring of activity, environmental pressures and impacts and the conservation of nature protection areas as actual or de facto marine protected areas (MPAs) (see sect. 3).

There have been recent technological developments for controlling the consequences of sea level rise, with increasing estuarine barriers and hard defences, nature-based solutions, habitat creation and the setback of defences. However, the continued loss of mangroves and other protective vegetation reduces coastal protection from both sea level rise and increasing storminess and storm surges. Where sea defence costs outweigh the value of the assets being protected, communities are encouraged to move back from the coast; however, a lack of financial capability in less-developed, low-lying areas, such as the Sundarbans in India and Bangladesh, prevents such adjustment.

Technological improvements in fisheries extraction reduce by-catch, and improved aquaculture technologies allow for the movement of mariculture and windfarms offshore. A move from fixed to floating cages and turbines and underwater current turbines enables exploitation of deeper waters, i.e. increased marine industrialization. Ocean carbon capture and storage technologies as well as CO_2 removal are being trialled (Joint Group of Experts on the Scientific Aspects of Marine Pollution (GESAMP), 2019, 2025), as are hydrogen storage technologies for energy created by renewable sources.

The offshore oil and gas industry is undergoing a major transformation as fields are exhausted or deemed unnecessary. Injection techniques extract the remaining oil and gas but the major transition is through decommissioning, including decisions on whether to remove, leave or topple the rigs and jackets in place, and to leave or remove pipelines and cables. For example, "rigs to reefs" programmes, with their advantages and disadvantages for local biodiversity, and investment in decommissioning technologies are being considered in oil- and gas-producing areas in the Gulf of Mexico, the North Sea and South-East Asia.

Changing governance structures and geopolitical instability

With neoliberalism on the rise, nationalism and protectionism continue to increase, according to the Democracy Index,[17] with notable politically motivated real or threatened trade tariffs and agreements. The

[16] See www.untourism.int/news/international-tourism-reached-97-of-pre-pandemic-levels-in-the-first-quarter-of-2024.
[17] See www.eiu.com/n/campaigns/democracy-index-2020.

Index fell from 5.55 in 2014 to 5.44 in 2019 and 5.37 in 2020, driven largely by the regional deterioration of conditions in Latin America and sub-Saharan Africa. This is the lowest global score since the first index in 2006, and has significantly deteriorated, occurring largely, but not solely, as a result of government-imposed restrictions on individual civil liberties worldwide in response to the COVID-19 pandemic.

The fall in the global score in 2020 reflected declines in average regional scores worldwide, especially a large decline in the regions of sub-Sahara, North Africa and the Middle East dominated by "authoritarian regimes", where scores declined by 0.09–0.10 points between 2019 and 2020. Average regional scores have declined during the lifetime of the Democracy Index: in both Western and Eastern Europe by 0.06; in Asia and Australasia, the region that has made the most democratic progress, by 0.05; in Latin America by 0.04 in 2020, marking the fifth consecutive year of regression for the region; and in North America by only 0.01,(reflecting a larger decline of 0.04 in the United States of America and an improvement for Canada. There remain large regional differences: countries in Scandinavia, the far north of North America (Canada and the northern United States) and the South-West Pacific had the highest indices, while those in sub-Saharan Africa, the Middle East and parts of Asia had the lowest.

These changes have an impact on the adoption of global, regional and national treaties, agreements and legal instruments, thereby affecting economic growth, technological developments and use, and ocean governance, and hence the use and users of the marine environment.

The Organisation for Economic Co-operation and Development (OECD) Better Life Index (OECD, 2020) reflects societal quality based on 11 topics (housing, income, jobs, community, education, environment, civic engagement, health, life satisfaction, safety and work-life balance) as indicators of the ultimate drivers of basic human needs and improved human health and welfare. Between 2010 and 2020, and following the financial collapse in 2008, overall longevity, income, employment and life satisfaction increased, as there were fewer people in overcrowded households. However, there are large and wider inequalities within and between countries, in resources for future well-being (in economic, natural and social capital) and in health outcomes and the environment. Coastal and marine natural, economic and social risks, especially climate change, biodiversity loss and threats to democratic processes, are threatening future well-being.

Cooperation between regional and international organizations increases the ability to tackle transboundary issues, facilitating coherence and equivalence across jurisdictional boundaries (Elliott and others, 2023).

The governance of marine nature conservation and restoration areas varies regionally and geographically. There are geographical disparities in their adoption despite the increase in nature conservation designations and other areas of designated importance (area-based management tools. These include MPAs and other effective conservation measures and their expansion beyond territorial waters (Amorim and Elliott, 2026) (see sect. 3). In addition, ecologically and biologically significant areas, while not designations in themselves, provide crucial scientific guidance for identifying areas of ecological value and are increasingly used as de facto designated areas for conservation, as in Canada.

Climate change, biodiversity and pollution

Climate change pressures show considerable geographical variability, with many areas warming, and ocean acidification, sea level rise and biodiversity patterns changing with species migrations, ultimately affecting societies (UNEP, 2024) (see sect. 4, chap. 3; and subsect. 5B, chap. 2). National responses to climate change are shaped by policy priorities, including alignment with international climate agreements such as the Paris Agreement and domestic approaches to energy transition.

Climate change effects vary geographically and create hotspots defined according to their vulnerability and the rate of change of their climatic conditions (Fan and others, 2021). These include marine and coastal areas such as the Arctic, Western Africa, the central eastern coast of South America (Brazil to Uruguay), Antarctica, Indonesia and South-East Asia, the Persian Gulf and the Red Sea, and the eastern China area. These areas appear to be warming more quickly and are exposed to species migrations and other consequences of climate change.

These hotspots have to cope regionally and nationally with the consequences of climate change, whereas the causes have to be addressed globally and with coordinated action, including by China, the United States, India, Europe, the Russian Federation and Brazil, which in 2023 accounted for the majority of greenhouse gas emissions (UNEP, 2024).

Coastal areas, deltas and estuaries are especially vulnerable to increases in marine storminess, storm surges, catchment rainfall changes, marine heatwaves and hurricane frequency. Coupled with stressors from increasing coastal urbanization and industrialization, they cause infrastructure destruction. It is therefore necessary to focus on natural hazards that become risks when they affect human welfare. For example, annual numbers of hurricanes in the North Atlantic Ocean were: 2–9 in the 1980s; 3–11 in the 1990s; 3–15 in the 2000s; 2–12 in the 2010s; and 7–13 in 2020–2023.[18]

4. Outlook

Coastal urbanization and industrialization and ocean industrialization, and the economic repercussions thereof, are projected to continue increasing in all geographical areas, thereby providing food, shelter, employment, well-being and enjoyment, inter alia, as well as stressors. Informal settlements will proliferate around many cities in the global South, together with the exposure of low-lying coasts to sea level rise and climate-compounded risks in the coming decades and centuries (Barbier, 2015). Those activities each have a footprint in terms of the natural system, leading to increasing pressures footprints and even larger effects footprints (Elliott and others, 2020). Activities are accompanied by the increased technological exploitation of ocean resources, including wind and wave energy, biotechnology resources and minerals – the latter necessary for batteries in electric vehicles.

The range of climate change pressures, state changes and impacts on human welfare will continue at the present rate even if greenhouse gas production decreases. Technological advances aimed at increasing adaptation to global warming using methods in, below or above the oceans may progress beyond the development stage (GESAMP, 2019, 2025). Further coastal defences will be required to combat storm surges, flooding and erosion. The effects of climate change will have an impact on the structure and functioning of ecosystems and ultimately the creation and use of societal goods and benefits.

As well as geopolitical instability, national, regional and global demographics will change with economic migration, varying fertility rates and notable ageing populations in the global North and an increasingly youthful population in the global South; these will all have an impact on coastal and marine ecosystems

[18] See https://tropical.atmos.colostate.edu/Realtime/index.php?arch&loc=northatlantic.

and the extraction of marine resources. Governance changes at the local, national, regional and global levels need to be vertically integrated (from the local to the global level and vice versa) and horizontally integrated across the main sectors of sustainable inclusive ocean economies. Governance instruments require coordination and funding to deliver marine use sustainably and stressors will require monitoring, modelling and management. Many national administrative and statutory bodies will be increasingly responsible for protecting marine areas and species using several nature conservation designations, including in areas beyond national jurisdiction.

The Agreement under the United Nations Convention on the Law of the Sea on the Conservation and Sustainable Use of Marine Biological Diversity of Areas beyond National Jurisdiction, which entered into force on 17 January 2026, will play a crucial role in governing areas beyond national jurisdiction. While the Convention primarily upholds the principle of freedom of the high seas, the Agreement is designed to ensure the sustainable use and conservation of marine biodiversity in areas beyond national jurisdiction, through effective implementation of the relevant provisions of the Convention and further international cooperation and coordination. Its implementation, including capacity-building and the transfer of marine technology, and area-based management tools are expected to enhance cooperation among stakeholders, reinforcing collective responsibility in addressing challenges in areas beyond national jurisdiction.

The value of sustainable inclusive ocean economies has been estimated at a minimum of $1.5 trillion per year, which is projected to double by 2030, with total ocean assets (natural capital) estimated at $24 trillion .[19] This will be achieved by means of existing and new technologies, especially as renewable energy generation replaces fossil fuel extraction, which is facing the economic and environmental challenges of decommissioning. Shipping will be able to exploit new Arctic polar sea routes (specifically the Northern Sea Route and the North-West Passage) due to an increase in ice-free periods; however, this will expose formerly pristine areas to pollution threats and increase NIS spread. Short-sea transport, especially inshore ferry routes, may use alternative fuels, such as energy stored in batteries.

The marine system and its ecosystem structure, function, services, goods and benefits are subject to local, national, regional and global risks and hazards, including shocks. These create, modify and disrupt the drivers, activities and pressures discussed in the present chapter. Most notably, the COVID-19 pandemic had major economic adverse repercussions, although some activities were restricted temporarily, such as fishing, tourism, maritime transport and supply chains, and manufacturing, resulting in decreased contamination and greenhouse gas emissions.[20] However, economies have mostly recovered and in some sectors, such as international travel and tourism, activity is now back to pre-pandemic levels. The short-, medium- and long-term effects of the pandemic on marine ecosystems and the uses and users of the seas have yet to be fully realized.

5. Key remaining knowledge and capacity gaps

The drivers, activities and pressures described in the present chapter interact, and although the single effects are well known conceptually and qualitatively, if not quantitatively, the cumulative synergistic and antagonistic effects are poorly understood (Korpinen and others, 2019). The spatial and temporal

[19] See https://thecommonwealth.org/bluecharter/sustainable-blue-economy.
[20] See www.carbonbrief.org/analysis-coronavirus-has-temporarily-reduced-chinas-co2-emissions-by-a-quarter.

quantification of activity, pressures and effects footprints is still lacking but is needed to quantify the overall human footprint on the marine system.

A holistic, integrated assessment, management and governance system is needed for the sustainable use and protection of the marine environment as a socioecological system (Elliott and Kennish, 2024; Bograd and others, 2019; Smith and others, 2025). This ensures that national, regional and global economies are protected and that the well-being of growing populations is assured. Both the ecosystem-based approach, operationalized by ecosystem-based management, and the precautionary approach, are therefore important. These are supported by adopting fit-for-purpose monitoring systems linked to quantitative indicators, which will indicate what type of management is required and also whether management has been effective (Elliott and others, 2025) (see sect. 3). Despite this, ecosystem-based management is only one of several approaches as governance imperatives (Glavovic, 2024).

The prediction of effects relies on detailed field and laboratory science coupled with modelling, including end-to-end models linking natural functioning and socioeconomic outputs. Furthermore, monitoring and management systems should be effective in all regions and areas. This detailed science then needs to inform policy, and vice versa. Transferring marine science and management technologies and approaches across geographic areas, especially from the global North to the global South, will have positive outcomes. In particular, such capacity-building will create sustainably managed global oceans and seas.

Crucial in this wider context is the need to engage with marginalized groups, Indigenous Peoples, gender and other forms of inequity and injustice, as these realities drive unjust and unsustainable development. Overcoming the drivers and root causes of unjust and unsustainable coastal and ocean development is therefore not a technical problem but a socioeconomic and political challenge.

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